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The Reactive Bed Plasma System for Contamination Control

by Joseph G. Birmingham, Robert R. Moore and Tony R. Perry

Introduction

In August 1987, NASA provided the Plasma Group at the Chemical Research, Development and Engineering Center (CRDEC) a list of chemicals including liquids, vapors, and particulates that are anticipated to cause contamination problems aboard the Space Station (1). CRDEC has selected several of these compounds to test an invention described as the Reactive Bed Plasma reactor. The objective of this paper is to summarize the contamination control capabilities of the Reactive Bed Plasma (RBP) system by delineating the results of toxic chemical decomposition studies, aerosol filtration work, and other testing.

Description of Reactive Bed Plasma

The Reactive Bed Plasma (RBP) was invented at the Chemical Research, Development and Engineering Center (CRDEC) to provide breathable air in chemical and biological warfare environments. The RBP is a synergistic combination of a plasma (or ionized gas) and catalytic technologies to produce an air purification system. The catalytic packing material's main function is to facilitate an increased amount of time in the active plasma region for contaminant molecules in a flowing air stream. The plasma generated high energy electrons and subsequently produced species decompose toxic materials. In addition, the RBP can perform as a highly efficient electrostatic precipitator to collect and eventually deactivate hazardous particulate material. Since, the RBP can handle toxic chemicals as well as hazardous aerosols, it can be described as an universal filter.

It is understood that trade-offs exist for any new technology. Some disadvantages of the RBP concept include the emission of electromagnetic noise (necessitating the shielding of the device), high voltage hazards and the treatment of reaction products. The advantages of the RBP include the potential for operating as an efficient, low temperature, long-lived, minimal energy-consumption, universal contamination control device.

Toxic Chemical Decomposition Studies

The list of chemicals provided by NASA included liquids and gases such as chlorinated compounds (such as hydrochloric acid, trichloroethane and chlorine), organics (such as benzene), and others. The RBP system has been tested against several compounds including cyanogen chloride (2), phosgene (3) and benzene (4). These test gases allow the contamination control capability of the RBP to be extrapolated to many chemical groups. Each gas's decomposition results reveals an important attribute of the RBP system. The efficient decomposition of cyanogen chloride demonstrated that the RBP did not exhibit the

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characteristic poisoning mechanisms of catalysts. Additionally, the phosgene results indicated that the RBP utilizes low temperatures (around 150 degrees C) and its performance does not degrade quickly. Also, any hydrochloric acid formed was converted to chlorine (as expected from a low temperature process). Finally, the benzene testing showed that the RBP can easily decompose organics flowing in ar air stream. The main reaction products from these decomposition studies include carbon dioxide and water, salts, and small amounts of acid gases (including halogens from the parent compounds and nitrogen dioxide from the air stream). The RBP has demonstrated the potential as a low temperature, efficient and universal decomposition system for hazardous compounds in a flowing air stream.

Aerosol Processing in RBP

Particulate materials on NASA's Contamination Control list include Polystryene Latex Spheres, microbes(which might include Bacillus Globigi spores and T-2 mycotoxin), and semiconductor processing aerosols. The Reactive Bed Plasma (RBP) reactor combines electrostatic precipitation with a packed bed to form a new aerosol filtration device. The testing of the RBP with Polystryene Latex spheres revealed that the RBP was a more efficient filter than for the empty plasma reactor (electrostatic precipitator) or a single packed bed (5). The biological aerosol challenges of the RBP including Bacillus Globigi spores (a heat resistant simulant for pathogenic species) and T-2 mycotoxin demonstrated efficient deactivation and decomposition, respectively (6). The RBP could become an ultrafiltration device with the incorporation of a ceramic High Efficiency Particulate Aerosol (HEPA) filter. Therefore, the RBP has the potential to become an aerosol filtration device for many applications.

Post-treatment of RBP Effluent

The requirement to neutralize any products found in the reactor effluent will be undertaken in the post-treatment section of the RBP system. Two approaches of removing the reaction products are packed beds and gas separation membranes. First, packed beds consisting of reactive material coated onto alumina support spheres has demonstrated the efficient removal of nitrogen dioxide and chlorine. This packed bed system will undergo additional testing. Next, some contamination control applications would allow a gas separation membrane to separate products to undergo further treatment in a scrubber solution. Since post-treatment burdens for contamination control are minimal, the solutions suggested may be adequate.

Contamination Control Approach Utilizing an RBP

The Reactive Bed Plasma (RBP) system has demonstrated the capability of efficiently processing many of the chemicals suggested by NASA. The ability to process liquids will require vaporization of the contaminate materials. This phase change may require the use of heat and air to introduce the hazardous

material into the RBP. Alternately, waste gases can be processed directly. Additional work is required to meet the stringent size, weight and volume constraints of the Space Station. Nevertheless, it is believed that the Reactive Bed Plasma system can provide contamination control for many applications.

Summary

The Reactive Bed Plasma (RBP) system has demonstrated its unique capabilities to decompose toxic materials and process hazardous aerosols. The post-treatment requirements for the reaction products have possible solutions. Although additional work is required to meet NASA requirements, the RBP may be able to meet Contamination Control problems aboard the Space Station.

References

1. Letter from R.J. Schwinghamer dated August 17,1987.

2. Moore,R.R., Birmingham, J.G.,"The Decomposition of Toxic Chemicals in a Low Temperature Plasma Device", Proceedings of the International Congress on Hazardous Materials Management, June 1987, Chattanooga, TN, pp 48-58.

3. Moore, R.R., "Toxic Chemical Decomposition in a Low Temperature Plasma Reactor", Proceedings of the 1987 U.S. Army CRDEC Scientific Conference on Chemical Defense Research, November 1987, Aberdeen Proving Ground, Md.

4. Birmingham, J.G., Moore,R.R.,"The Determination of Decomposition Efficiency for Hazardous Waste Chemical Analogs in a Reactive Bed Plasma" Proceedings of the 1987 U.S. Army CRDEC Scientific Conference on Chemical Defense Research, November 1987, Aberdeen Proving Ground, Md.

5. Henderson, P.E., Birmingham, J.G., Moore, R.R., Johnson, A.W., "Determination of the Aerosol Filtering Efficiency of a Reactive Bed Plasma" Proceedings of the 1987 U.S. Army CRDEC Scientific Conference on Chemical Defense Research, November 1987, Aberdeen Proving Ground, MD.

6. Henderson, P.E., Birmingham, J.G., Moore, R.R., Beaudry, W.T.,"Biological Aerosol Decomposition in a Reactive Bed Plasma (RBP) Reactor" Proceedings of the 1987 U.S. Army CRDEC Scientific Conference on Chemical Defense Research, November 1987, Aberdeen Proving Ground, MD.

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Reactive Bed Plasma Presentation

I. Introduction

II. Toxic Chemical Decomposition

III. Aerosol Filtration

IV. Post-Treatment of Reactor Effluent

V. Contamination Control Application

REACTIVE BED PLASMA DEFINITION AND OBJECTIVE

- REACTIVE BED PLASMA: The synergistic coupling of plasma (or ionized gas) and catalysis
- OBJECTIVE: To develop and demonstrate Reactive Bed Plasma technology to treat pollutants released into the environment
- GOAL: Technology Transfer to industry

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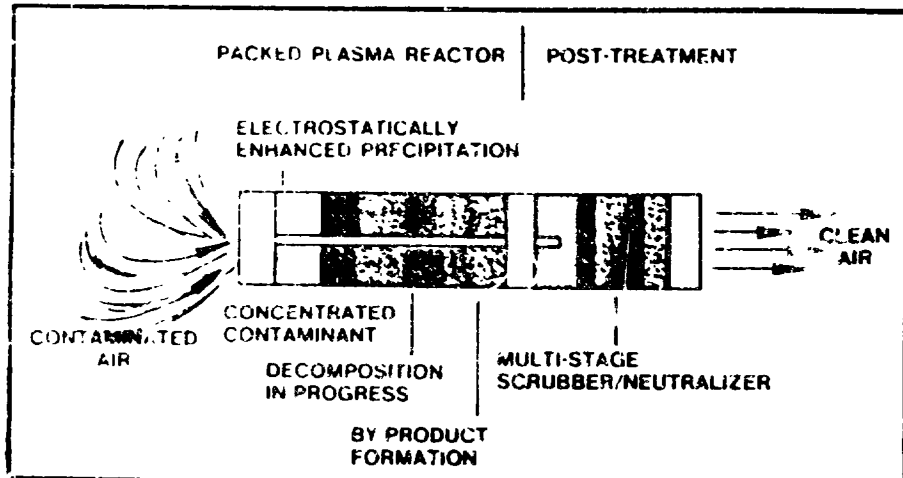
REACTIVE BED PLASMA

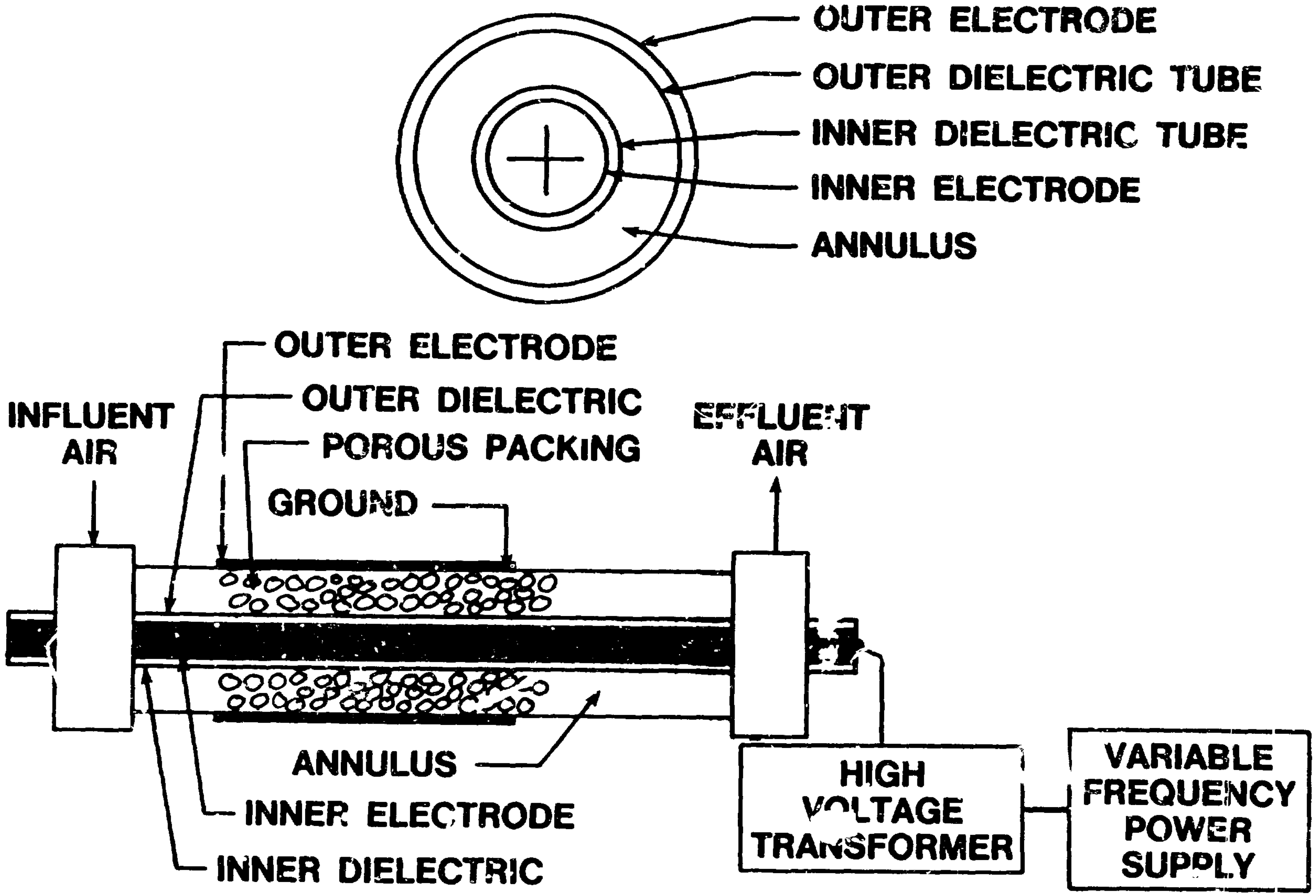


- PLASMA IS AN ELECTRICALLY NEUTRAL, HIGHLY IONIZED GAS COMPOSED OF ELECTRONS AND IONS

STATUS

- LABORATORY INVESTIGATIONS ONGOING TO ESTABLISH TECH DATA BASE ON REACTION MECHANISMS AND POST-TREATMENT
- [illegible] SCALE-UP
- [illegible] AND POST-TREATMENT

REACTIVE BED PLASMA



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Reactive Bed Plasma Presentation

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$\boxed{\text{II. Toxic Chemical Decomposition}}$

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Contamination Materials

- Liquids including:
  - Acids (Acetic, Nitric, Hydrochloric, Perchloric, Hydrofluoric)
  - Organics (Benzene, Xylene, Toulene, Phenol, Trimethyl Benzene)
  - Hydrocarbons (Methanol, Trichloroethylene, Acetone, Dichloromethane, Trichloroethane)
  - Others

Contamination Materials

- Gases including:
  - Air Components (Oxygen, Nitrogen, Argon, Helium, Hydrogen)
  - Light Hydrocarbons (Methane)
  - Carbon Monoxide / Carbon Dioxide
  - Freons (Freon 22, Freon 113)
  - Acid Gases (Chlorine, Fluorine)
  - Others

RESULTS

CHEMICAL PROCESSING	% DECOMPOSITION
GD (Nerve Agent)	> 99.8 %
AC (Hydrogen Cyanide)	> 99.4 %
*CK (Cyanogen Chloride)	> 99.6 %
Cyanogen	> 99.8 %
Methyl Cyanide	98 %
*CG (Phosgene)	> 99.84 %
Carbon Monoxide -> Dioxide	84 %
Methane	> 97 %
**Benzene	97.85 %

* RBP

** Experimental RBP

">" LIMIT OF DETECTION

CHEMICAL PROCESSING RESULTS

MATERIAL / DURATION	CONCENTRATION	FLOW RATE	RESIDENCE	EFFICIENCY
CK (Cyanogen Chloride)				
115 min	1576 ppm	2.6 cfm	0.44 sec	> 99.6 %
CG (Phosgene)				
78 min	200 ppm	5.5 cfm	0.31 sec	> 99.84 %
Benzene				
64 min	177 pp	2.0 cfm	0.92 sec	97.85 %

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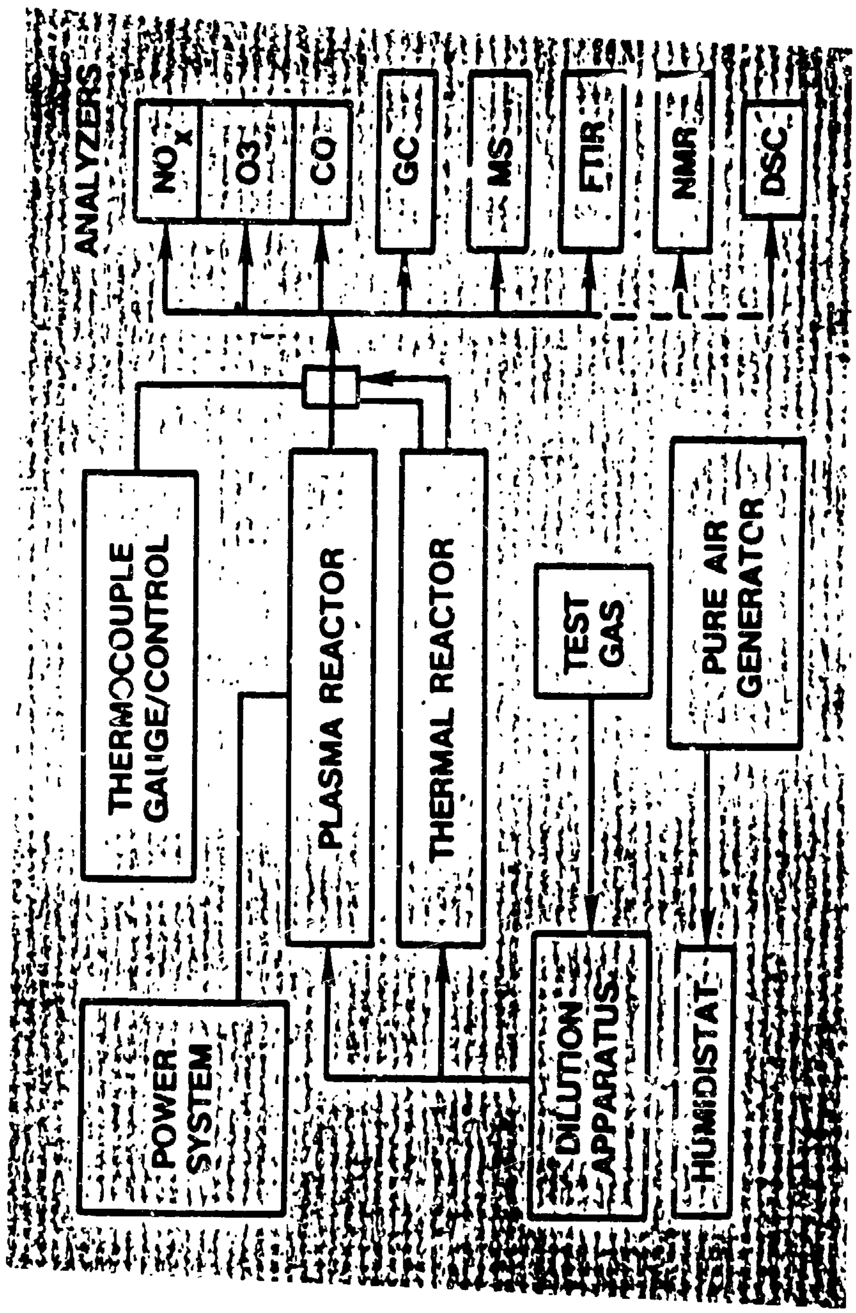
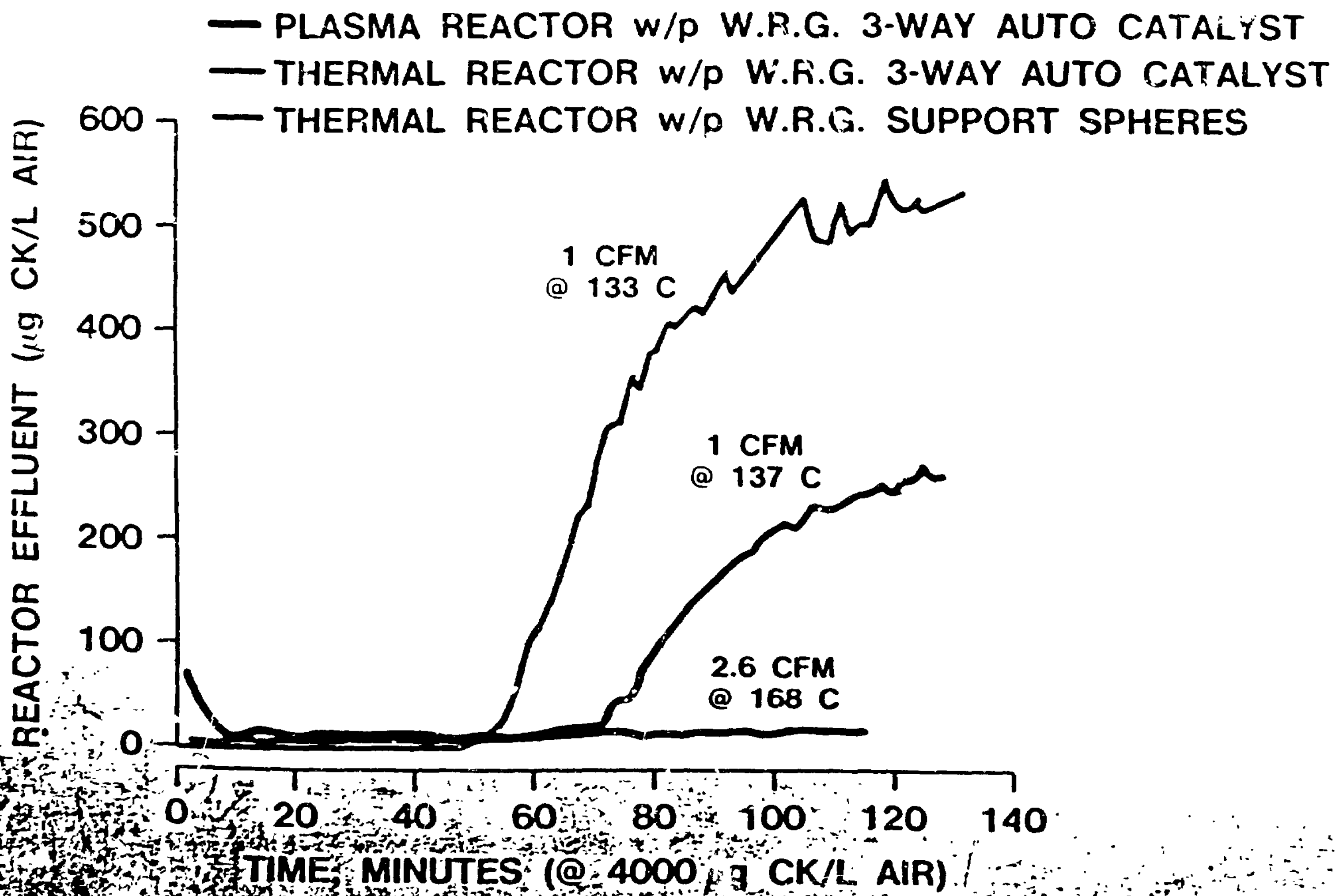

ANALYZERS
NO$_x$
O3
CO
GC
MS
FTIR
NMR
DSC
THERMOCOUPLE GAUGE/CONTROL
PLASMA REACTOR
THERMAL REACTOR
TEST GAS
PURE AIR GENERATOR
POWER SYSTEM
DILUTION APPARATUS
HUMIDISTAT

COMPARISON OF REACTIVE BED PLASMA AND THERMAL REACTORS



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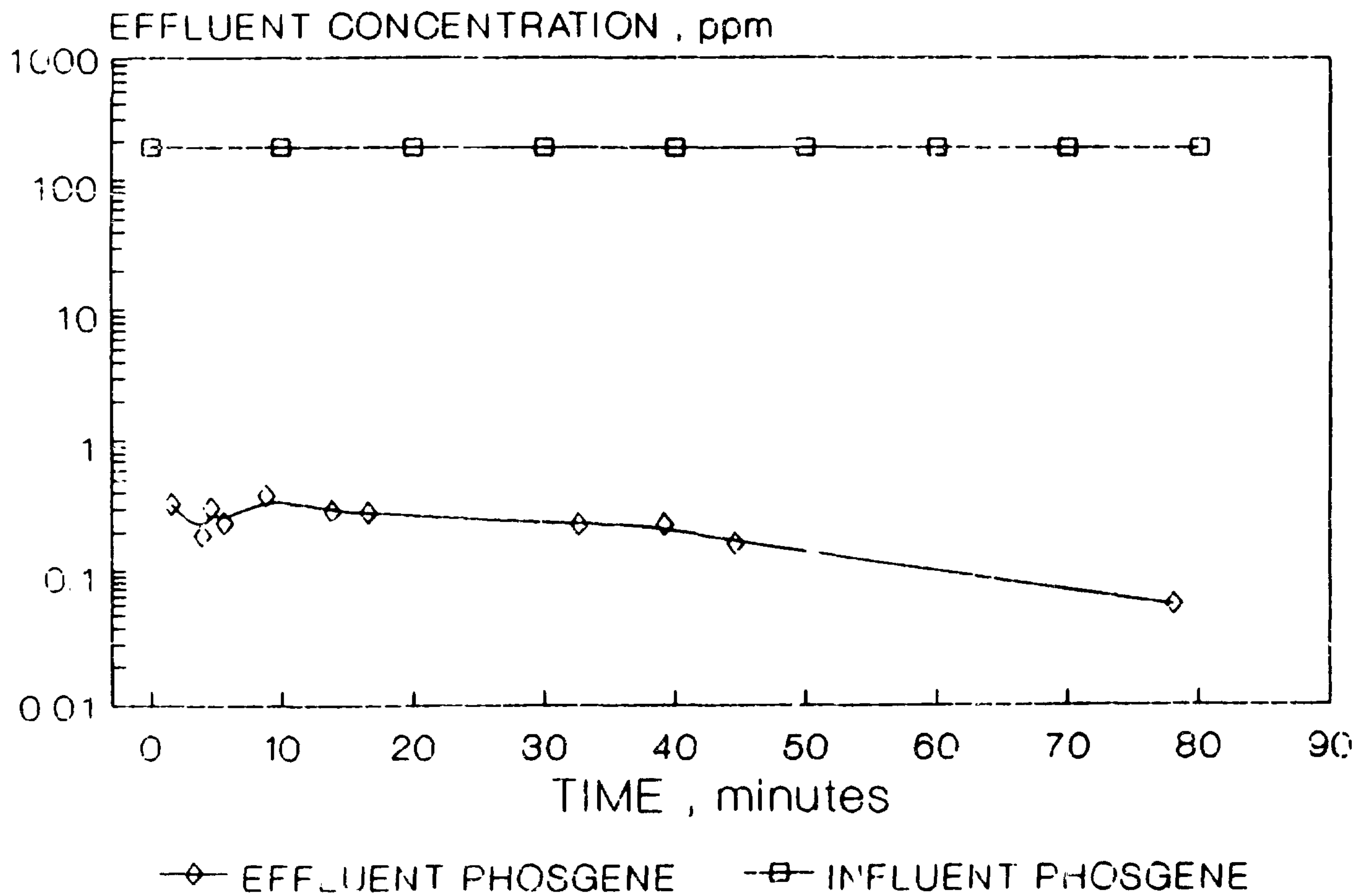
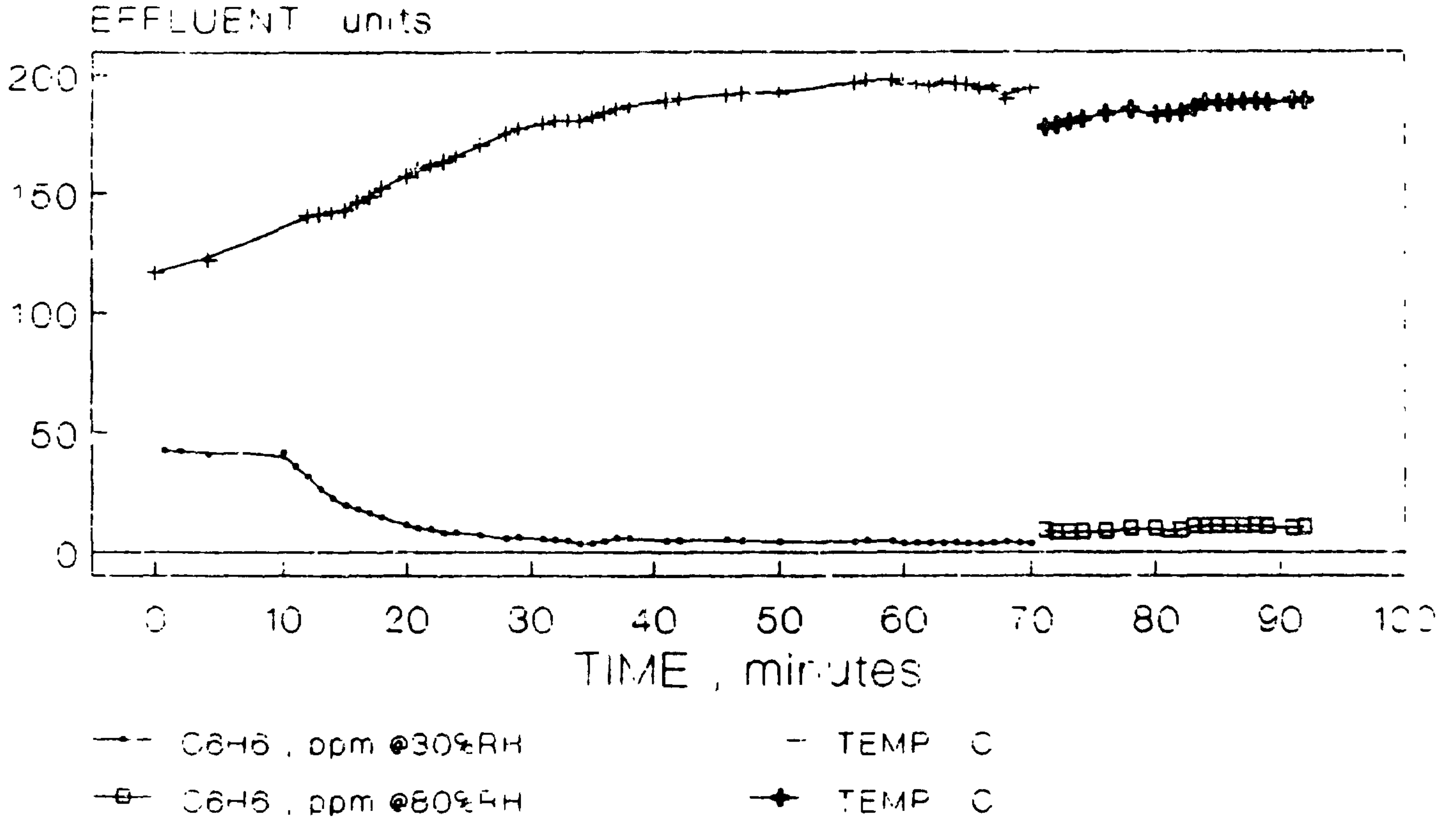
PHOSGENE DECOMPOSITION



Challenge: 200 ppm $COCl_2$ in Air

BENZENE DECOMPOSITION IN A REACTIVE BED PLASMA



Challenge: 177 ppm Benzene @ 2.0 CFM Air
Applied Power: 1000 watts

ADVANTAGES OF RBP TECHNOLOGY

- Low Temperature Process for minimal power consumption
- Highly Efficient Decomposition of most groups of toxic chemicals
- RBP does not exhibit characteristic catalyst poisoning mechanisms

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DISADVANTAGES OF RBP TECHNOLOGY

- Scale-up of technology from 10 CFM to 100 CFM
- Requires post-treatment for reaction products in some applications

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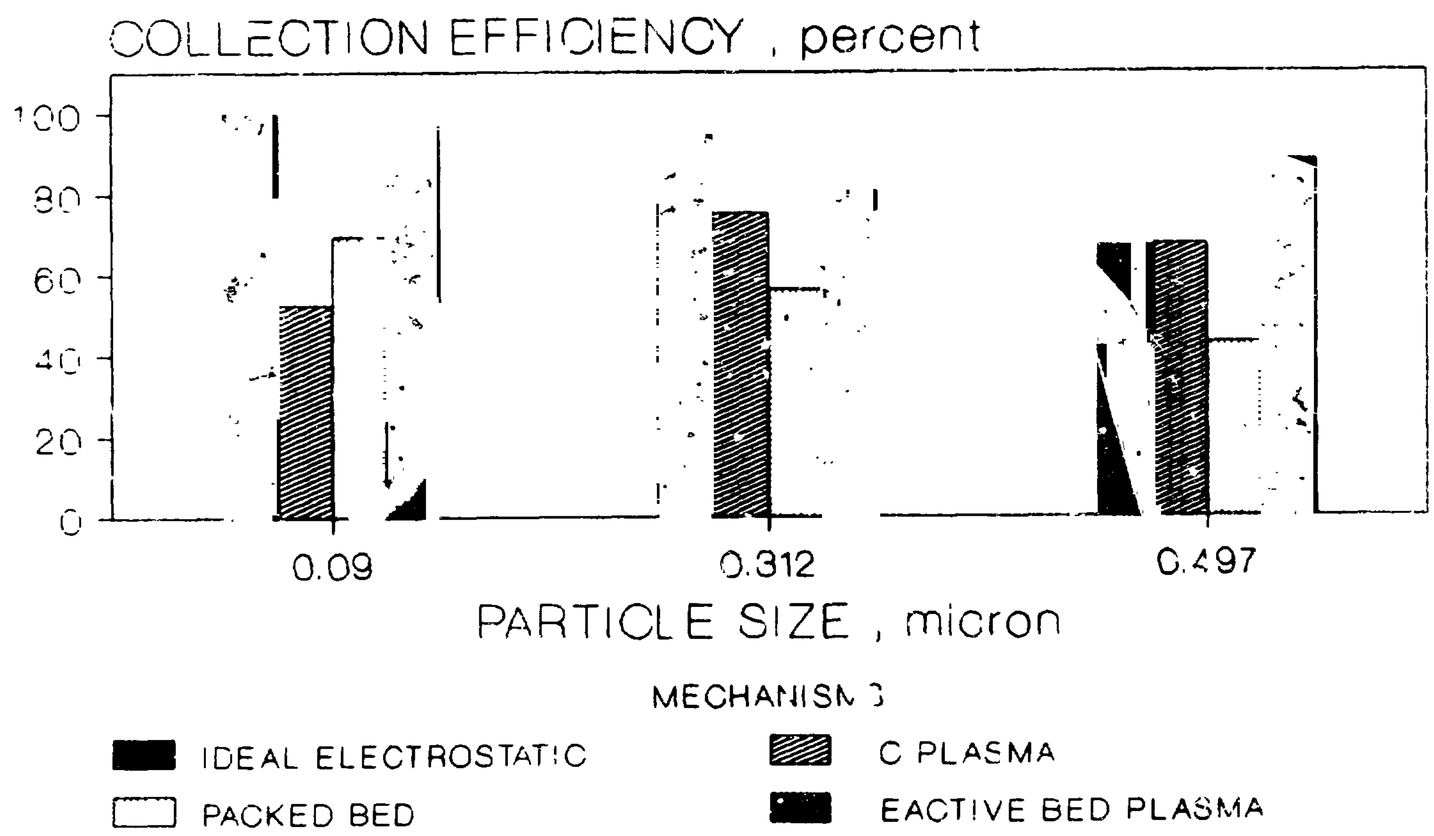
Contamination Materials

- Particulates including:
  - * Semiconductor Processing (Germanium, Silicon, Gallium Arsenide)
  - * Latex Spheres
  - * Microbes
  - * Others

AEROSOL REMOVAL MECHANISMS OF POLYSTYRENE LATEX SPHERES



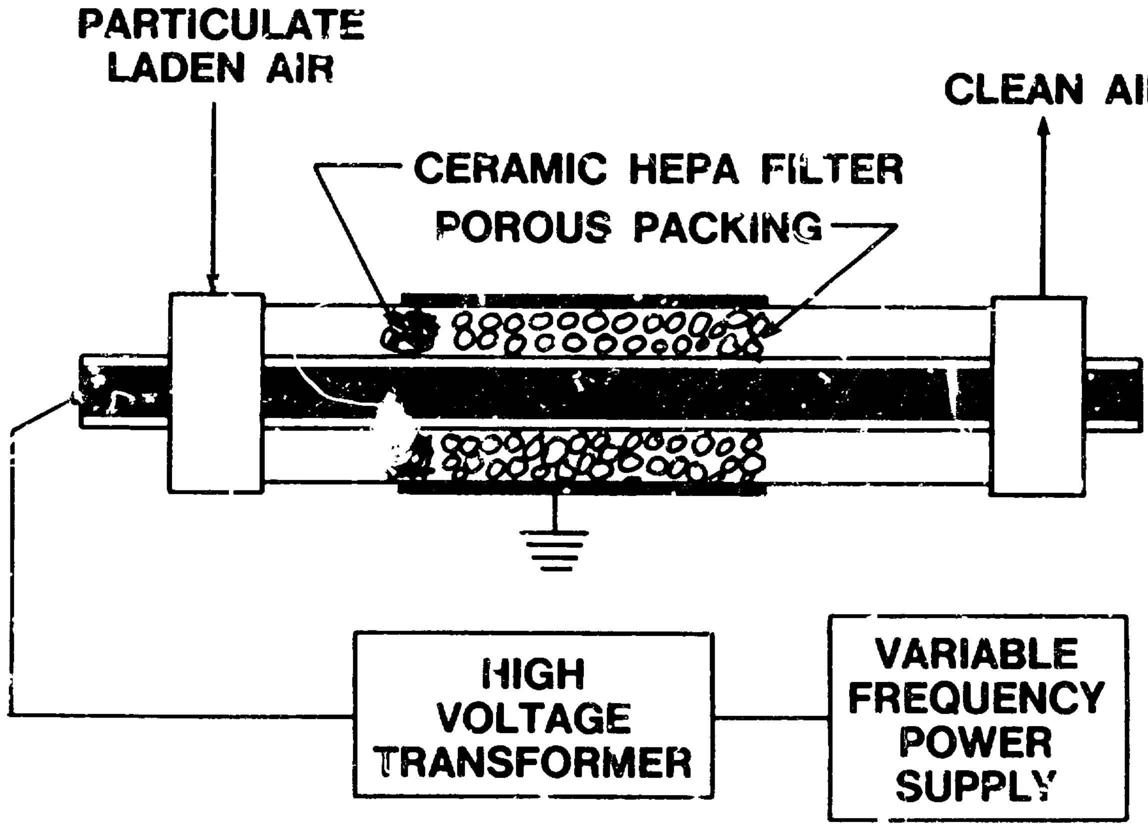
RESULTS

BIOLOGICAL PROCESSING	% DEACTIVATION
*BG SPORES	> 99.9999 %

BIOCHEMICAL PROCESSING	% DECOMPOSITION
*T-2 MYCOTOXIN	>99.72 %

*> LIMIT OF DETECTION

CONFIGURATION OF ULTRA HIGH EFFICIENCY RBP AEROSOL COLLECTION SYSTEM



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Air By-Product Formation in RBP

Air By-Product	Concentration (ppm)
Nitrogenous Oxides (NOx)	60
Ozone (O3)	< .01
Carbon Monoxide (CO)	< 1

REACTION PRODUCTS
CLASSES AND REMOVAL TECHNIQUES

$ClCN + 2H_2O \rightarrow NH_4Cl + CO_2$	LIQUID SCRUBBER, PACKED BED, OR PARTICULATE FILTER
$COCl_2 + O^* \longrightarrow Cl_2 + CO_2$	LIQUID SCRUBBER OR PACKED BED
$C_6H_6 + 15(O^*) \longrightarrow 6CO_2 + 3H_2O$	NONE
$N_2 + 2O_2 \longrightarrow 2NO_2$	LIQUID SCRUBBER OR PACKED BED

INORGANIC SALT : NH_4Cl

INORGANIC ACID GAS : Cl_2 & NO_2

POST-TREATMENT

PACKED BED ALUMINA) (10 cm bed depth @ 88 °C)

MATERIAL				
DURATION	CONCENTRATION	FLOW	RESIDENCE	REMOVAL
CHLORINE (Cl_2)				
40 min	140 ppm	28.3 lpm	0.15 sec	96%
NITROGEN DIOXIDE (NO_2)				
35 min	100 ppm	10.1 lpm	0.42 sec	95%

GAS SEPARATION MEMBRANE (N_2/O_2 SEPARATION)

NITROGEN OXIDES (NO_2/NO)			O_2 ENRICHMENT (5 lpm)
60 min	250/56 ppm	45/5 lpm	+8% NO_2, +60% NO

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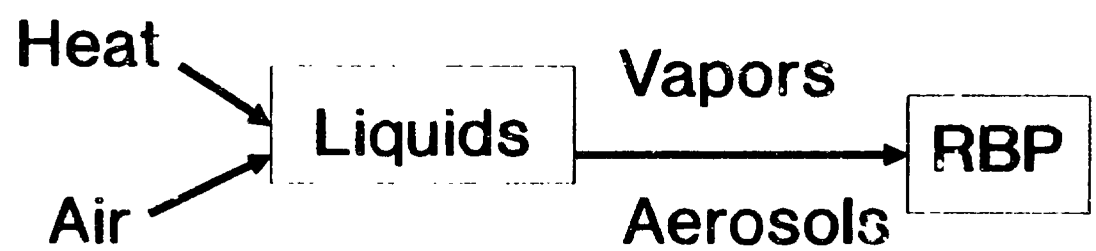
RBP Contamination Control

Liquid Processing:



Gas Vapor and Particulate Handling: